The Transparency Universe: Instructions

Goal: To visualize the universe expanding in all directions, and to predict Hubble's law.

Materials:

Student grouping: groups of 2 students; can be larger. For each group:

- Galaxy Field 1 on paper, and Galaxy Field 2 on transparency
- Worksheet and graph sheet
- transparency marker, ruler

Introduction:

Students will model the expansion of space by seeing how galaxies on a flat sheet of paper have moved 'between two ticks of a cosmic clock'. Students will use rulers to measure distances between galaxies, to find out what happens to them when space expands. They will find that there is a specific pattern to how the galaxies appear to move: that their apparent speed of motion away from the observer is proportional to their distance.

Procedure:

- Students should work through part 1 of the worksheet in their groups.
- Each group chooses a home-galaxy on Galaxy Field 1, and lays Field 2 over it. They observe the motion of other galaxies, and note down their observations.
- A short class discussion can take place after part 1.
- Students then work on part 2. A home-galaxy is chosen again, and a transparency marker is used to draw an arrow on Field 2 from each galaxy's position on Field 1 to its position on Field 2. Blue-tack can be used to stop the sheets from slipping.
- Students measure the distance each galaxy has moved, and how far it was initially from the home-galaxy. These distances are recorded in the table, and plotted on the blank graph provided.
- The class then gets together. Different groups feed back what they have found. After an initial discussion, collect all the Field 2 transparencies and pile them on top of each other on an overhead projector.

Discussion points:

- What is the pattern for how much each galaxy has moved?
  It is directly proportional to the distance from the home galaxy. The distance moved in a tick of a clock is the same as speed, so apparent speed is proportional to distance. This is Hubble's law.

- How does the conclusion change if you move galaxies?
  Everyone found the same result, even though they picked different home-galaxies.

- Is it possible for something to move at different speeds and directions?
  Students have drawn arrows in different directions for the same galaxy, and each home-galaxy seems to be the centre of the expansion. The only way this could happen is if space itself is expanding, rather than galaxies moving through space.

- How can we tell that other galaxies observe the same as we do?
  We can only observe from one home-galaxy (the Milky Way). But astronomers assume

that we are not in a special place in the universe, so every other place should observe the expansion just as we do.

- What happened in the past?
  If we wind time backwards, all of the galaxies would move closer and closer together. At some time in the past they would all be on top of each other. This is the Big Bang! (NB, galaxies weren't actually around at the Big Bang though – they formed later.). So, the Big Bang is not an explosion from one place, it is an expansion everywhere in space.

- How could we work out when the Big Bang happened in this transparency universe?
  Assuming the rate of expansion has stayed the same, the time since they were all on top of each other can be found by dividing the distance by the speed for any galaxy. This can be done on average by calculating the slope of the graph (v/d), and inverting it. The slope gives the rate of expansion, and is known as Hubble's constant. We suggest that measuring the slope is kept for a follow-up activity with real data.

- Why is there a scatter to the graphs?
  Due to measurement errors.

- What would they expect to see if the universe were not expanding? Or if it were shrinking?
  Not expanding: no motion, or very little. Shrinking: same pattern but arrows in opposite direction.

- What properties of galaxies would you need to go and measure if you wanted to know (a) if space if expanding, and (b) when the expansion began?
  You would need to be able to measure distances and apparent speeds of galaxies beyond our own. This is tricky in space! And is the subject of follow-up activities.

This activity is taken from Cosmic Questions: Our Place in Space and Time, by the Harvard-Smithsonian Center for Astrophysics. Minor adaptations for QUEST course by J. Dunkley, I. Levine.